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LAUNCH WINDOW CHARACTERISTICS OF THE 1972 AND 1973 JUPITER OPPORTUNITIES

by Tim J. Kreiter

Lewis Research Center
Cleveland, Ohio

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SUMMARY

The launch window characteristics of the 1972 and 1973 Jupiter opportunities were examined assuming an SLV-3X/Centaur-S/Burner II launch vehicle. It was found that for a 90° to 115° launch azimuth sector both the direct and indirect ascent launching modes provide launch windows for these opportunities.

If the Jupiter encounter were used to provide gravity assist, the probe could meet a secondary mission objective, such as a galactic probe or a close solar probe.

Earth injection energies for the 1972 and 1973 Jupiter opportunities can be reduced by increasing trip time, and no other energy saving schemes were uncovered.

INTRODUCTION

Jupiter, the largest planet in the solar system, will soon be the target of NASA unmanned spacecraft. According to present plans, Jupiter missions will be pursued in the early 1970's using a yet-to-be determined launch vehicle. In keeping with the existing family of NASA launch vehicles, one of the prime candidates for this mission is an uprated Atlas with an improved Centaur and a solid motor upper stage. Although detailed data regarding this launch vehicle are not

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yet finalized, an attempt has been made to define those performance parameters which are needed to conduct a preliminary mission analysis.

The primary purpose of this paper is to present direct and indirect ascent launch window parameters which typify Jupiter opportunities in the early 1970's. Herein, the 1972 and 1973 Jupiter opportunities were investigated assuming an SLV-3X/Centaur-S/Burner II launch vehicle. Launch window data were generated for selected days in the launch intervals for both the direct and indirect (parking orbit) ascent departure modes. In addition, a cursory analysis was made of two possible secondary mission objectives; namely, the galactic probe and the close solar probe.

An interplanetary trajectory program for the IBM 7094 computer was used to generate the Earth/Jupiter trajectories in this study. The orbits of the planets were assumed to be mutually inclined ellipses with time-variant orbital elements. A sphere-of-influence or patched conic approximation was made for the geocentric, heliocentric, and Joviocentric trajectories.

ANALYSIS

Booster Performance Assumptions

In order to provide useful launch window data for any given launch opportunity, it is important to define the booster powered flight characteristics inasmuch as they directly affect the launch window parameters, especially injection true anomaly for the direct ascent case and parking orbit coast time for the indirect ascent case.

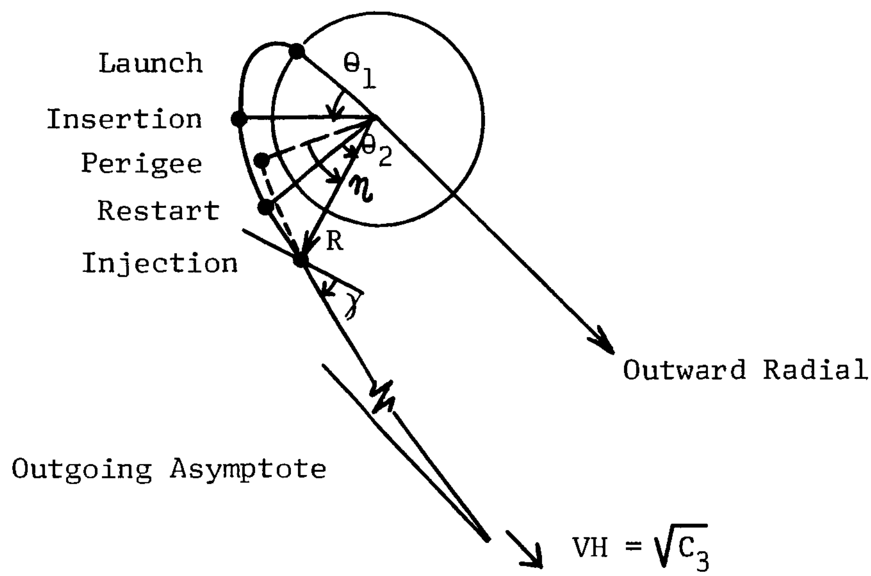
An ideal direct ascent launch window should exhibit optimum injection true anomalies (from a payload sense) when launches occur at launch azimuths in the vicinity of 90° to 115° East of North from ETR. If large departures from the 90° to 115° azimuth sector are required to obtain optimum true anomalies (maximum payload), range safety is compromised and practical launch windows may not exist.

Ideal indirect ascent launch windows should, for the 90° to 115° launch azimuth sector, exhibit parking orbit coast times which are commensurate with vehicle capabilities.

Typical optimized booster data have been generated for a preliminary version of the SLV-3X/Centaur-S/Burner II. Assuming a launch azimuth of 90° and a parking orbit altitude of 100 n.mi., the following indirect ascent (parking orbit) injection conditions were computed:

1.	C_3, vis-viva energy (square of hyperbolic excess speed)	101.597 Km^2/sec^2 (V_c = 49,000 fps)
2.	η, injection true anomaly	12.015°
3.	γ, flight path angle	8.756°
4.	R, radius	21.94931 x 10^6 ft.
5.	e, eccentricity of geocentric hyperbola	2.67801
6.	θ_1, powered flight arc, first burn	26.99°
7.	θ_2, powered flight arc, second burn	23.81°
8.	t_1, t_2, powered flight times, respectively	703.9 and 266.4 sec.

Sketch A depicts some of the above parameters.



Sketch A - Ascent Geometry

The generation of direct ascent trajectory data is not as straightforward as in the indirect ascent case, and a great deal more information (mission constraints, heating rate limits, etc.) must be known. A first order approximation for direct ascent trajectories, however, may be made by assuming that the total powered flight arc equals the sum of the first and second burn arcs for the indirect ascent case; i.e., 26.99° + 23.81° = 50.80°; and similarly, the powered flight time will be approximately 703.9 + 266.4 = 970.3 seconds.

For indirect ascent trajectories, injection true anomaly is for all practical purposes a constant; and for a given launch azimuth, payload capability is a function of injection energy. For direct ascent trajectories, however, injection true anomaly will vary throughout the daily launch window; and it has a strong influence on payload capability.

The exact variation of payload vs. true anomaly for a given day, which ultimately defines direct ascent launch windows is not presented in this paper, but this information will be generated as soon as direct ascent booster data becomes available. Herein, it is assumed that direct ascent launch window potential exists if the injection true anomaly requirement is near 12° for the 90° to 115° azimuth sector. This true anomaly (12°) was found to be near optimum for the indirect ascent case; and from previous experience, the optimum direct ascent true anomaly should not be significantly different.

RESULTS

Launch Window Considerations

The years chosen for analysis were 1972 and 1973, and a 20-day launch interval (approximating minimum energy) was selected. Data are presented for the first, middle, and final days of the intervals.

Figure 1 presents vis viva injection energy, declination of the outward radial (relative to the earth's equator) and the hyperbolic approach velocity at Jupiter encounter as functions of Earth-Jupiter time-of-flight for the various launch dates. The energy requirements are nearly the same for both years. The declinations (outward radial) for the1973 opportunity are more southerly (negative) than for the 1972 opportunity which results in less favorable launch azimuths as will be shown later. Approach velocities at Jupiter are between 9 and 13 Km/sec for both opportunities.

Direct Ascent Mode

The direct ascent launch window parameters, launch azimuth, and injection true anomaly are presented on figures 2a, 2b, and 2c as functions of time-of-launch for Earth-Jupiter trip times of 500, 550, and 600 days, respectively. The launch dates considered were February 26, March 6, and March 17, 1972. Note that the shapes of the azimuth curves on February 26 for 550-and 600-day trip times (figures 2b and 2c) are different from the others in that 90° launch azimuths are not possible. On these occasions, the absolute value of the declination (outward radial) exceeds the latitude of the launch site (about 28.3°) thereby precluding launches within a narrow band of 90°.

In general, the direct ascent mode appears feasible in 1972 as evidenced by the launch azimuth requirements for an injection true anomaly of 12° (the assumed optimum value from payload considerations). These are, roughly: 100°, 95°, and 90° for opening, middle, and closing days, respectively, assuming that trip times are between 500 and 600 days.

Figures 3a, 3b, and 3c depict direct ascent launch window data for the 1973 opportunity. Nowhere in the April 1 to April 21 launch interval (for 500- to 600-day trips) may launch azimuths of 90° be utilized. Furthermore, the longer the trip time, the wider the non-usable azimuth band. For example, the non-usable azimuth band for 500-day trips is about 85° to 95°. For 600-day trips, the non-usable azimuth band is about 75° to 105°. In spite of this, the direct ascent mode appears promising for the 1973 opportunity based on the fact that launch azimuths for 12° true anomalies lie between 100° and 113°.

Indirect Ascent Mode

The indirect ascent launch window parameters, launch azimuth, and parking orbit coast time are presented in figures 4a, 4b, and 4c as functions of time-of-launch for trip times of 500, 550, and 600 days, respectively. The launch dates depicted are February 26, March 6, and March 17, 1972.

Observe that for a given launch date there are two usable branches of the launch azimuth curve, meaning that two launch windows exist per day. The first branch is characterized by parking orbit coast times of less than or equal to 15 minutes for launch azimuths greater than or equal to 90°. The second branch, however, may exhibit 80 to 90 minute coast time requirements depending upon the launch azimuth in question. Either or both of these windows may be utilized assuming that the booster is designed for extended coast capability.

Indirect ascent launch window data for 1973 are shown in figures 5a, 5b, and 5c. The same azimuth limitations; i.e., non-usable azimuth bands, exist for indirect ascent trajectories as did for direct ascent trajectories inasmuch as the Earth-Sun-Jupiter geometry remains the same regardless of the geocentric ascent profile. The shapes of the azimuth curves in figures 5a, 5b, and 5c therefore resemble those in figures 3a, 3b, and 3c.

Unless waivers are obtained for north-easterly launches, only the second branch (or launch window) may be used for the 1973 opportunity. Coast times less than 10 minutes are required to generate launch windows for a portion of the second branch. Launch window may be further extended if 90-minute coast capability exists.

Secondary Mission Objectives

Consider a probe approaching Jupiter from a given direction with a hyperbolic approach velocity (relative to Jupiter) of $\overrightarrow{VH}_A$. After encountering Jupiter, the hyperbolic departure velocity (relative to Jupiter), $\overrightarrow{VH}_D$, is identical in magnitude to $\overrightarrow{VH}_A$, but it will have been turned through some angle, τ, due to the presence of Jupiter's gravitational field. Figure 6 presents this turning angle as a function of the hyperbolic approach velocity, $\overrightarrow{VH}$, for various approach distances from Jupiter. It can be seen from the figure that very fast probes at large distances from Jupiter are unperturbed.

The heliocentric velocity of the probe is given by the vector equation:

$$\overrightarrow{V}_P = \overrightarrow{V}_{♃} + \overrightarrow{VH}$$

where $\overrightarrow{V}_{♃}$ is Jupiter's orbital velocity and VH is the hyperbolic velocity relative to Jupiter. The heliocentric velocity of the probe, $\overrightarrow{V}_P$, can be drastically altered if the probe passes relatively close to Jupiter.

To illustrate the dramatic consequences of a Jupiter encounter, a specific Earth-Jupiter trajectory was selected for further analysis. The reference trajectory departs Earth on April 11, 1973, and requires 500 days to reach Jupiter. Its hyperbolic approach velocity at that time is 12.25 Km/sec relative to Jupiter.

The post-encounter geometry was computed and is summarized on figure 7. Pericenter radii of 5, 10, 15, 20, and 25 were assumed, and both leading and trailing edge encounters were considered. (See figure 7 for definitions.)

Trailing edge encounters are observed to increase the resultant heliocentric velocity thus promoting solar system escape. Leading edge encounters tend to reduce heliocentric velocities.

Galactic Probe

If the reference trajectory were to encounter Jupiter at an infinite distance (hence, be unperturbed by Jupiter), it would reach an aphelion distance of only 9 AU taking about 2000 days (from launch). But from figure 8, if Jupiter is encountered at 5 to 10 planet radii, the probe could reach 9 AU in about 1000 days; and, furthermore, it would ultimately escape the solar system. (Solar system escape velocity at Jupiter is about 18.5 Km/sec.)

The historical significance of the first solar system escape should not be overlooked. It would rank as fundamentally important as the first earth satellite, the first moon landing and the like.

Solar Probe

If the spacecraft were to encounter Jupiter's leading edge, the heliocentric velocity would be reduced to such an extent that it would fall back toward the sun. For the reference trajectory, a pericenter proximity of 5 Jupiter radii results in a perihelion distance of .097 AU about 528 days after the Jupiter encounter (1028 days after earth departure). A pericenter proximity of 10 results in a perihelion distance of .028 AU, 681 days after encounter (1181 days from earth departure).

The solar probe application is further illustrated in figures 9 and 10 which present perihelion distance and Jupiter-Sun trip time, respectively, as functions of Jupiter pericenter distance. An earth injection velocity of 49,250 fps ($C_3 \approx 104$) was used in generating the figure, and Earth and Jupiter were assumed to occupy circular coplanar orbits at radial distances from the sun equivalent to their semi-major axes.

From figure 9, it can be seen that, for the earth injection energy depicted, minimum perihelion distance (.0325 AU) is achieved by allowing the spacecraft to pass within 12 Jupiter radii of the planet. This is a reflection of the encounter geometry and the resultant heliocentric velocity components in the radial and tangential directions.

Energy Saving Schemes for Jupiter Flyby Missions

It has been suggested that gravity encounters with either Venus or Mars might be used to reduce energy requirements for Jupiter missions. No studies have been conducted at LeRC to substantiate this.

Niehoff (reference 1) has taken a preliminary look at this problem. In his analysis, he found that post-Venus trajectories never reached more than 3 AU from the sun even for characteristic velocities as high as 54,000 fps. When applied in a direct fashion, this velocity normally gives aphelions of 10 AU or better.

For Earth/Mars/Jupiter trajectories, a characteristic velocity savings of about 2000 fps over the direct Earth-Jupiter mode was demonstrated in reference 1 for 500-600 day trip times. Hyperbolic velocities at Mars were observed to be double that of typical Mars probe values which would seem to minimize the value of any Mars experiments enroute. Furthermore, the next favorable Earth/Mars/Jupiter opportunity is shown to occur in 1984. The modest energy savings provided by a Mars gravity encounter, together with very infrequent launch opportunities, diminish the importance of this mission mode; and it was not included in the present investigation.

CONCLUDING REMARKS

A preliminary study has revealed that direct and indirect ascent launch windows appear to exist for the 1972 to 1973 Jupiter opportunities.

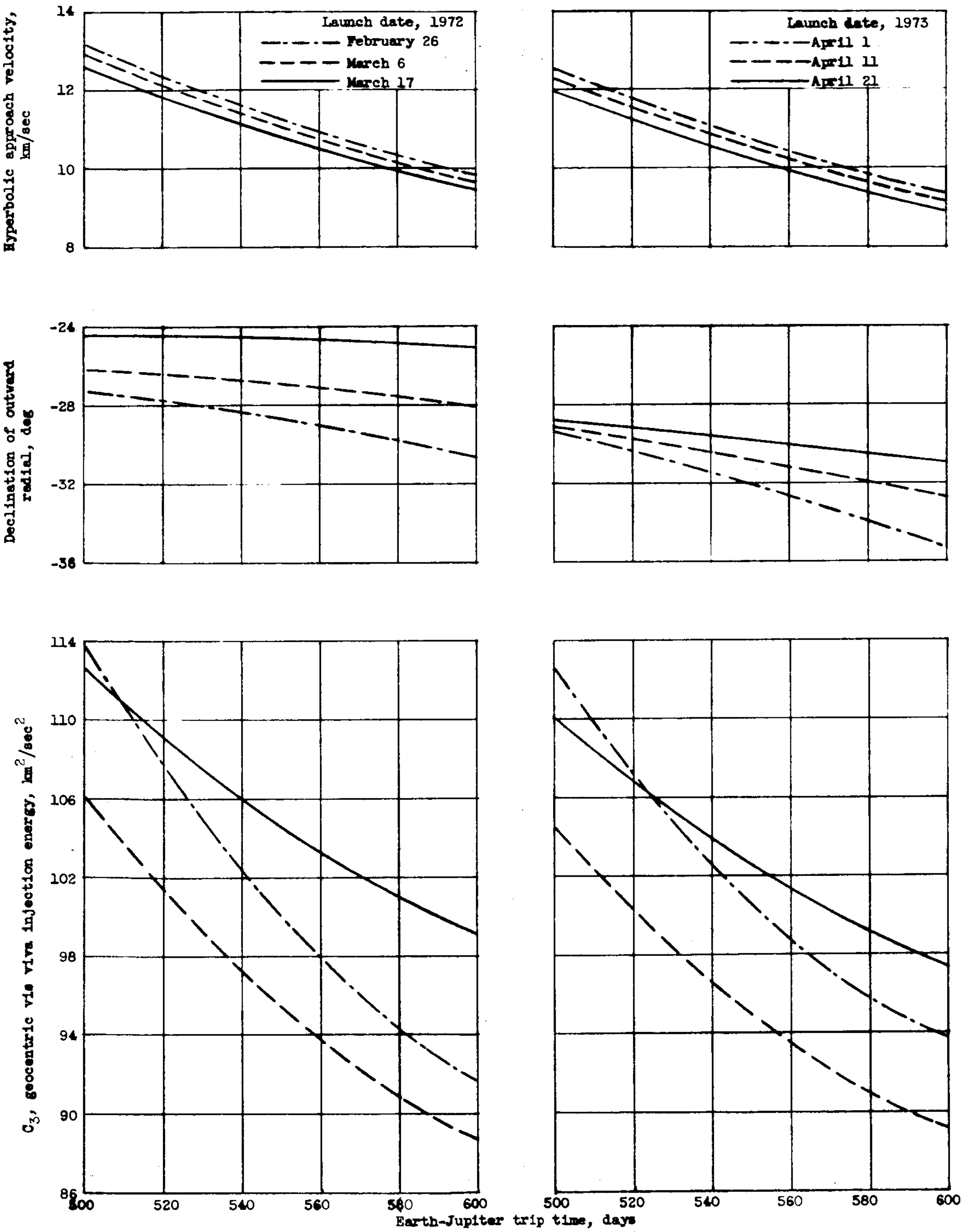
If encounter distances are discreetly chosen, the spacecraft may achieve a secondary mission objective such as a galactic probe or a close solar probe.

No apparent energy reduction schemes have been uncovered as yet for these opportunities other than increasing Earth-Jupiter trip times.

REFERENCES

1. Niehoff, John C.: An Analysis of Gravity Assisted Trajectories to Solar System Targets, AIAA Paper No. 66-10, January 1966.

Lewis Research Center
National Aeronautics and Space Administration
March 21, 1967



(a) 1972 opportunity.

(b) 1973 opportunity.

Figure 1. - Vis viva energy, declination of outward radial and hyperbolic approach velocity as functions of trip time for 1972 and 1973 Jupiter opportunities.

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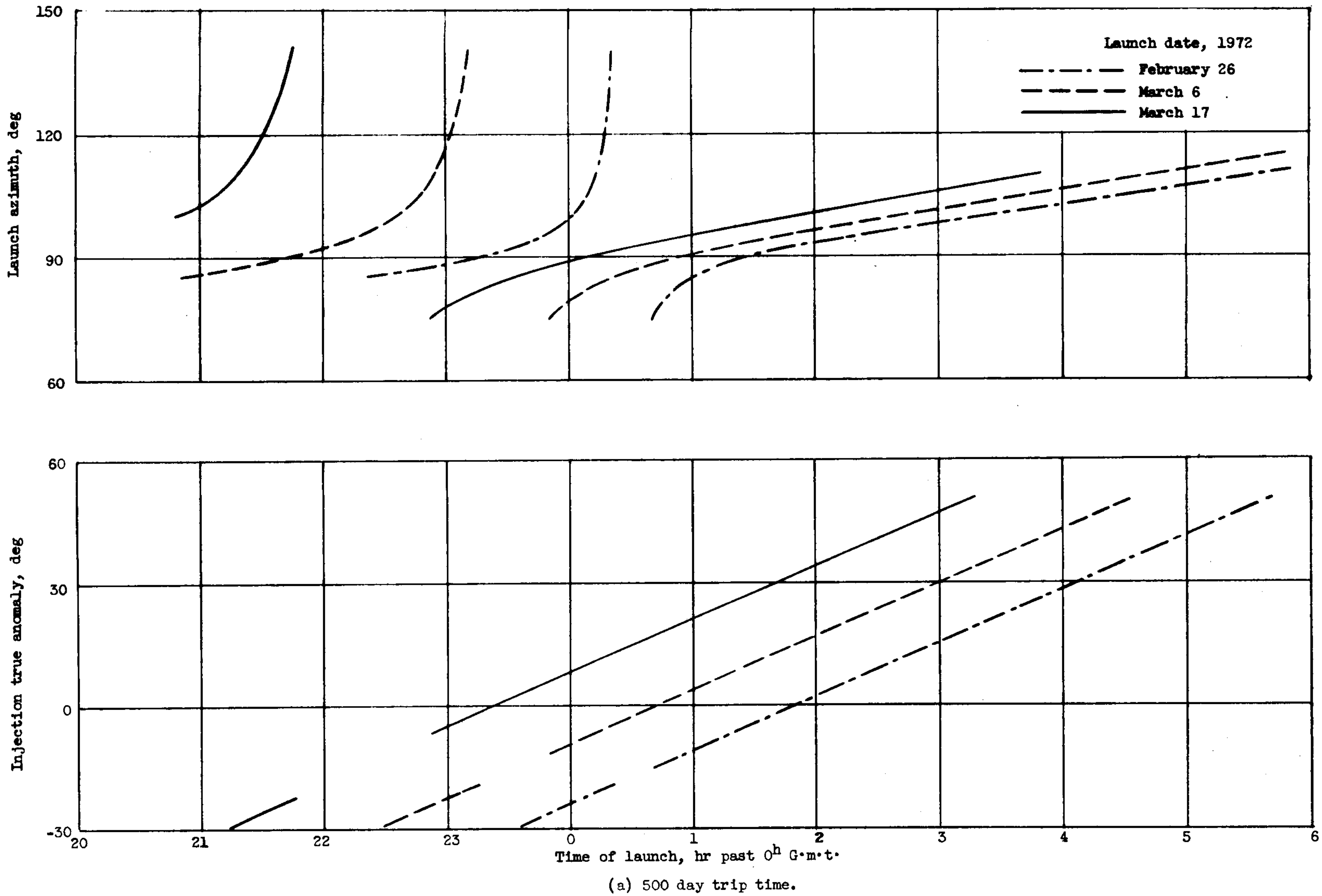

(a) 500 day trip time.

Figure 2. - Launch azimuth and injection true anomaly as functions of time of launch for direct ascent Jupiter trajectories. 1972 opportunity.

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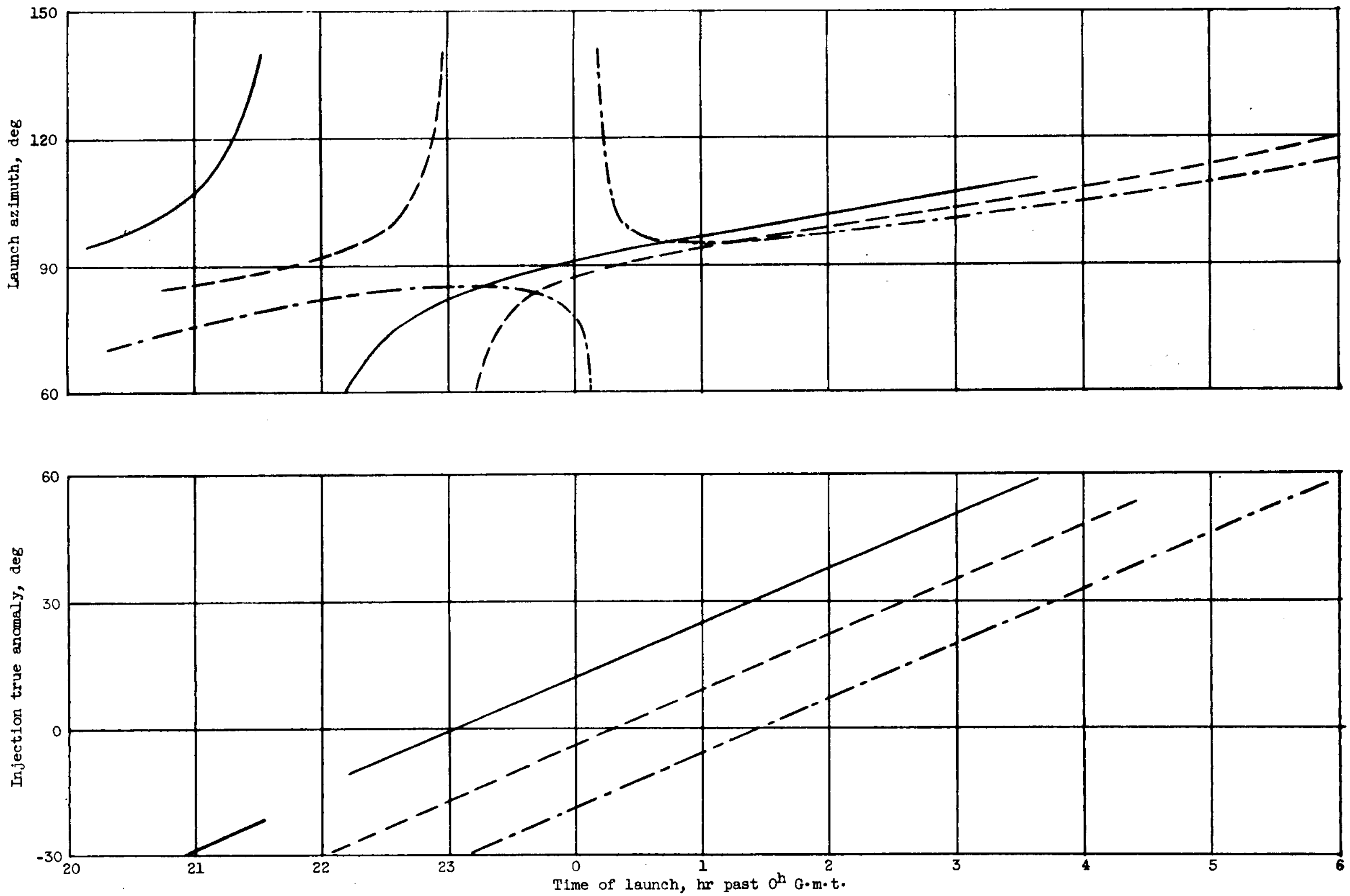

(b) 550 day trip time.

Figure 2. - Continued. Launch azimuth and injection true anomaly as functions of time of launch for direct ascent Jupiter trajectories. 1972 opportunity.

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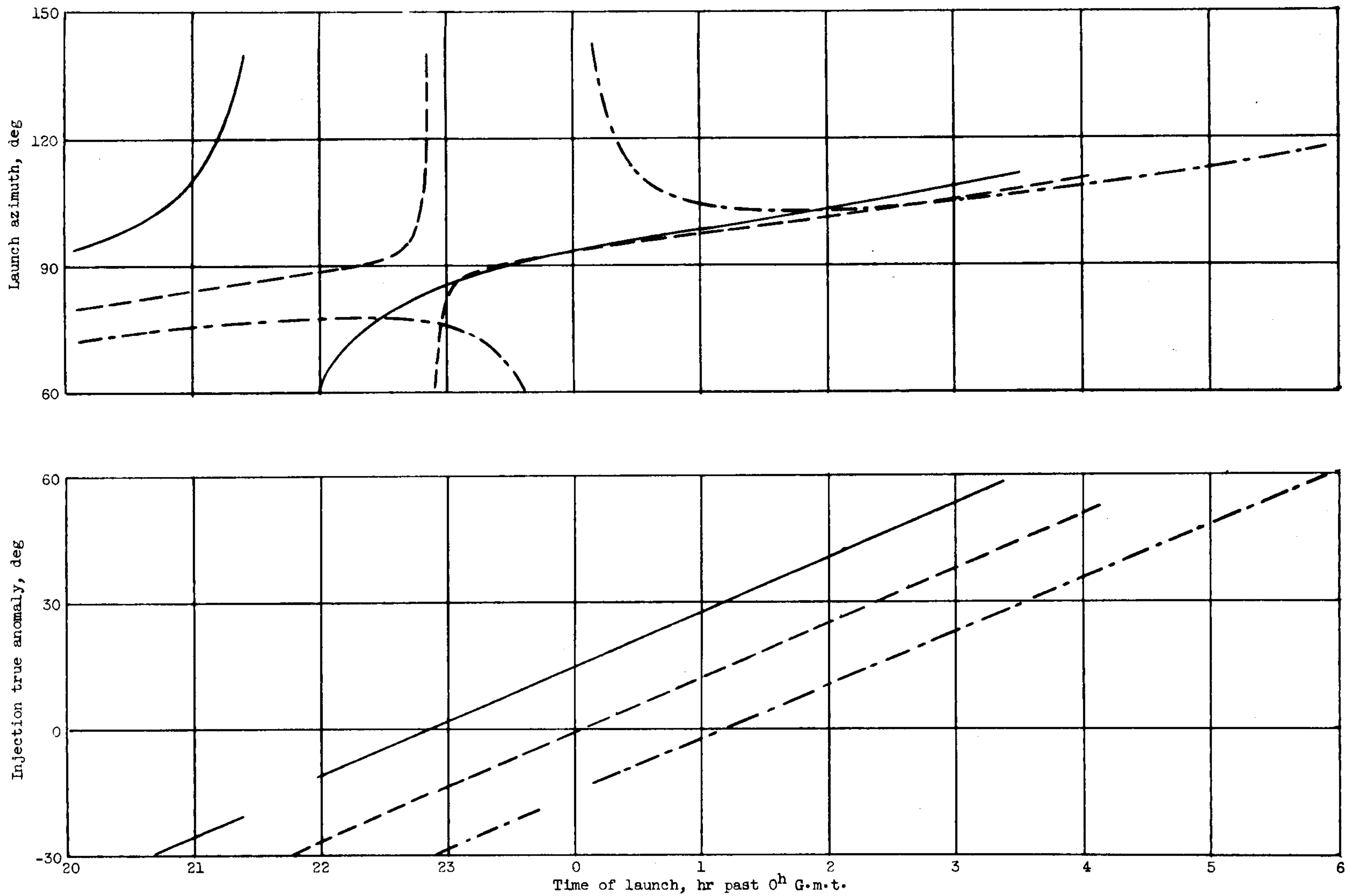

(c) 600 day trip time.

Figure 2. - Concluded. Launch azimuth and injection true anomaly as functions of time of launch for direct ascent Jupiter trajectories. 1972 opportunity.

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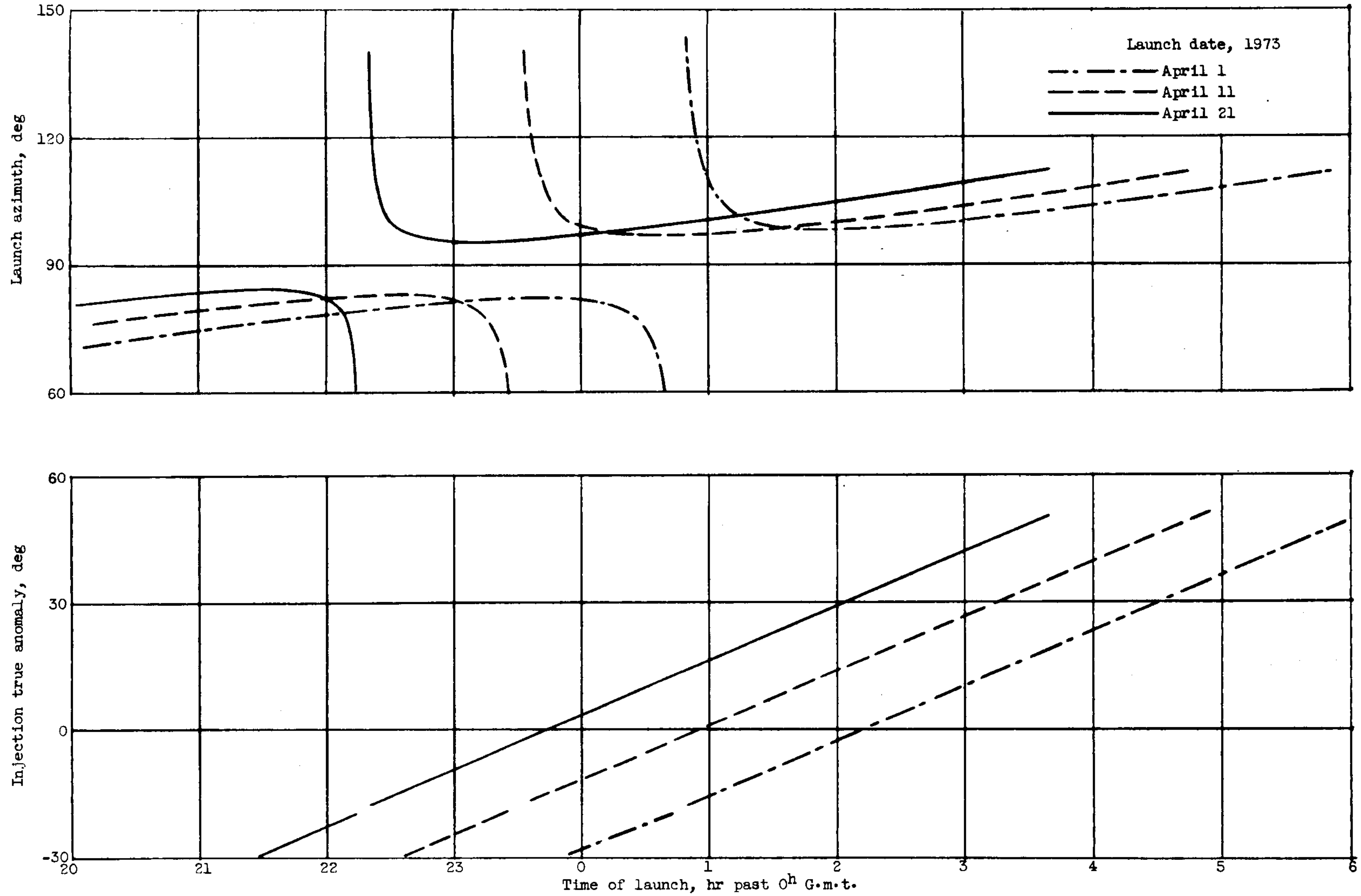

(a) 500 day trip time.

Figure 3. - Launch azimuth and injection true anomaly as functions of time of launch for direct ascent Jupiter trajectories. 1973 opportunity.

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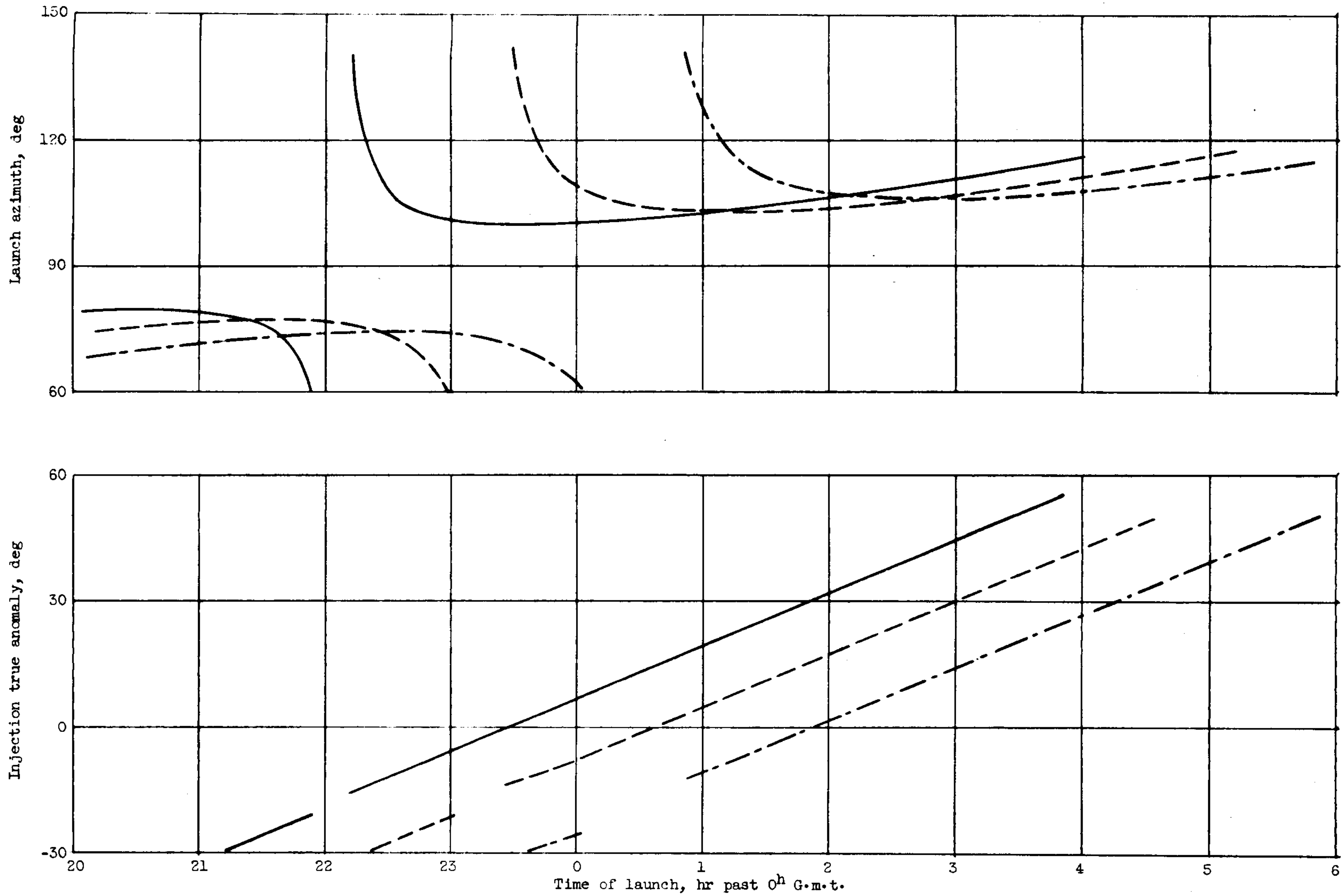

(b) 550 day trip time.

Figure 3. - Continued. Launch azimuth and injection true anomaly as functions of time of launch for direct ascent Jupiter trajectories. 1973 opportunity.

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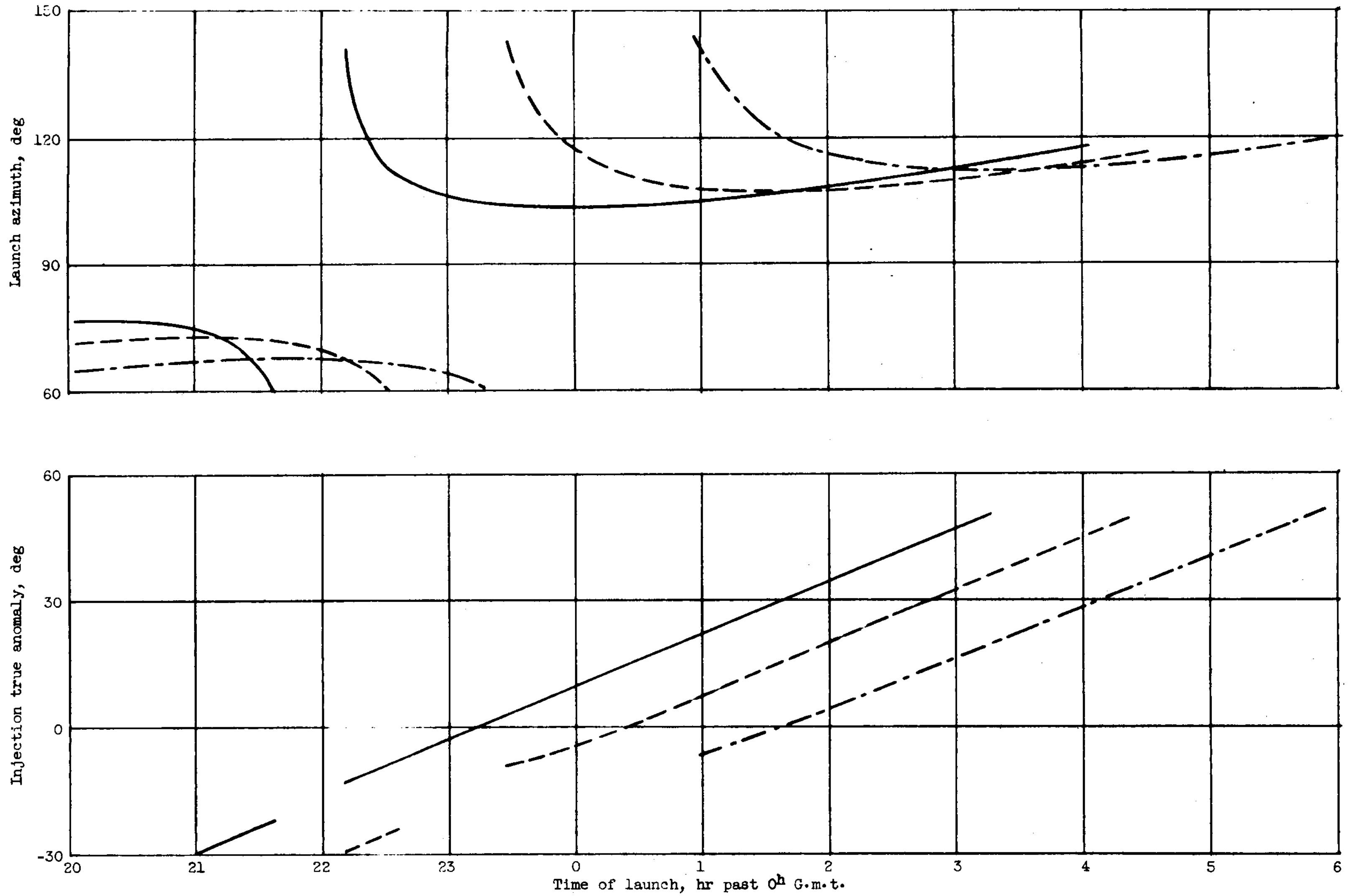

(c) 600 day trip time.

Figure 3. - Concluded. Launch azimuth and injection true anomaly as functions of time of launch for direct ascent Jupiter trajectories. 1973 opportunity.

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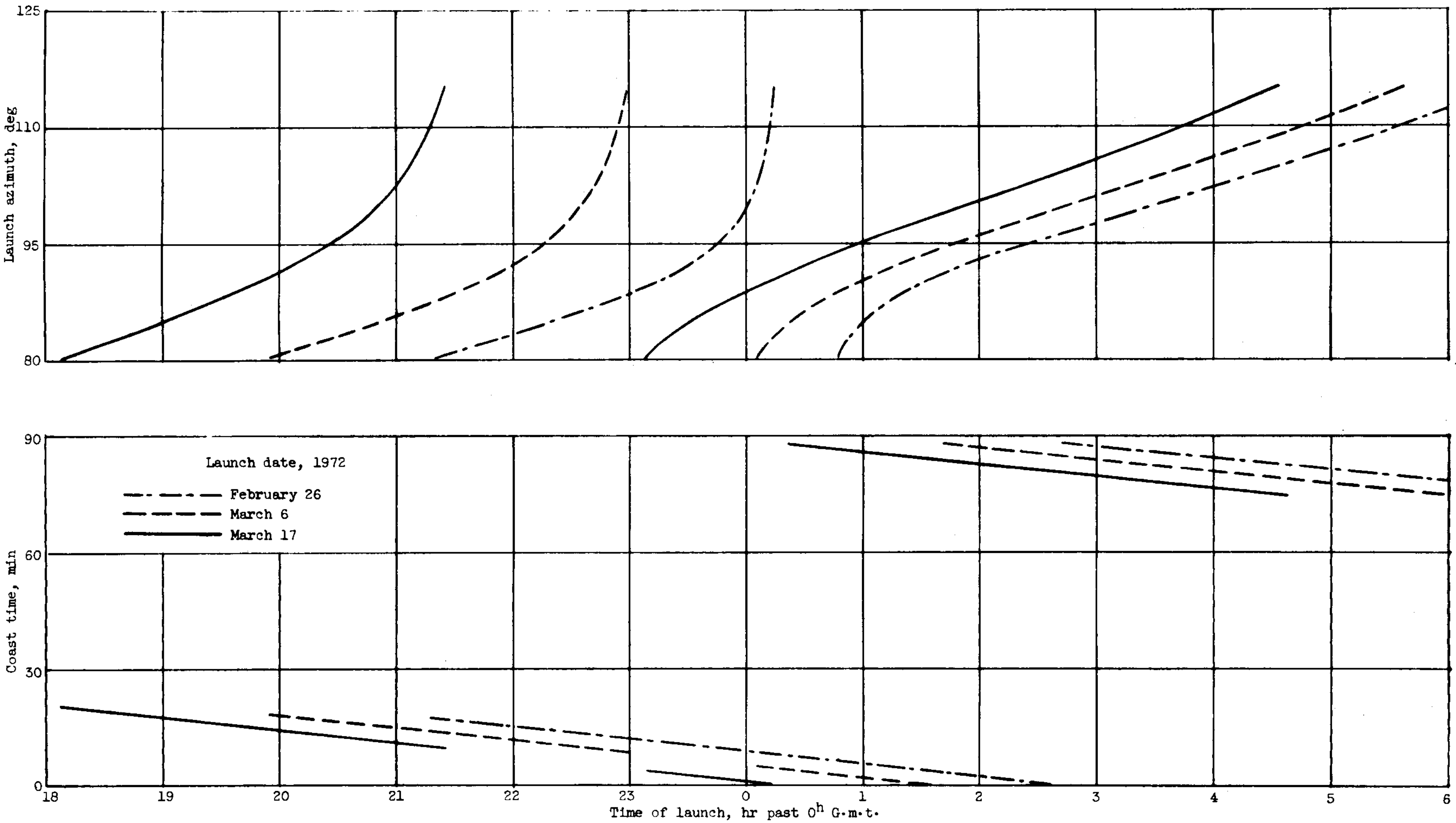

(a) 500 day trip time.

Figure 4. - Launch azimuth and parking orbit coast time as functions of time of launch for indirect ascent Jupiter trajectories. 1972 opportunity.

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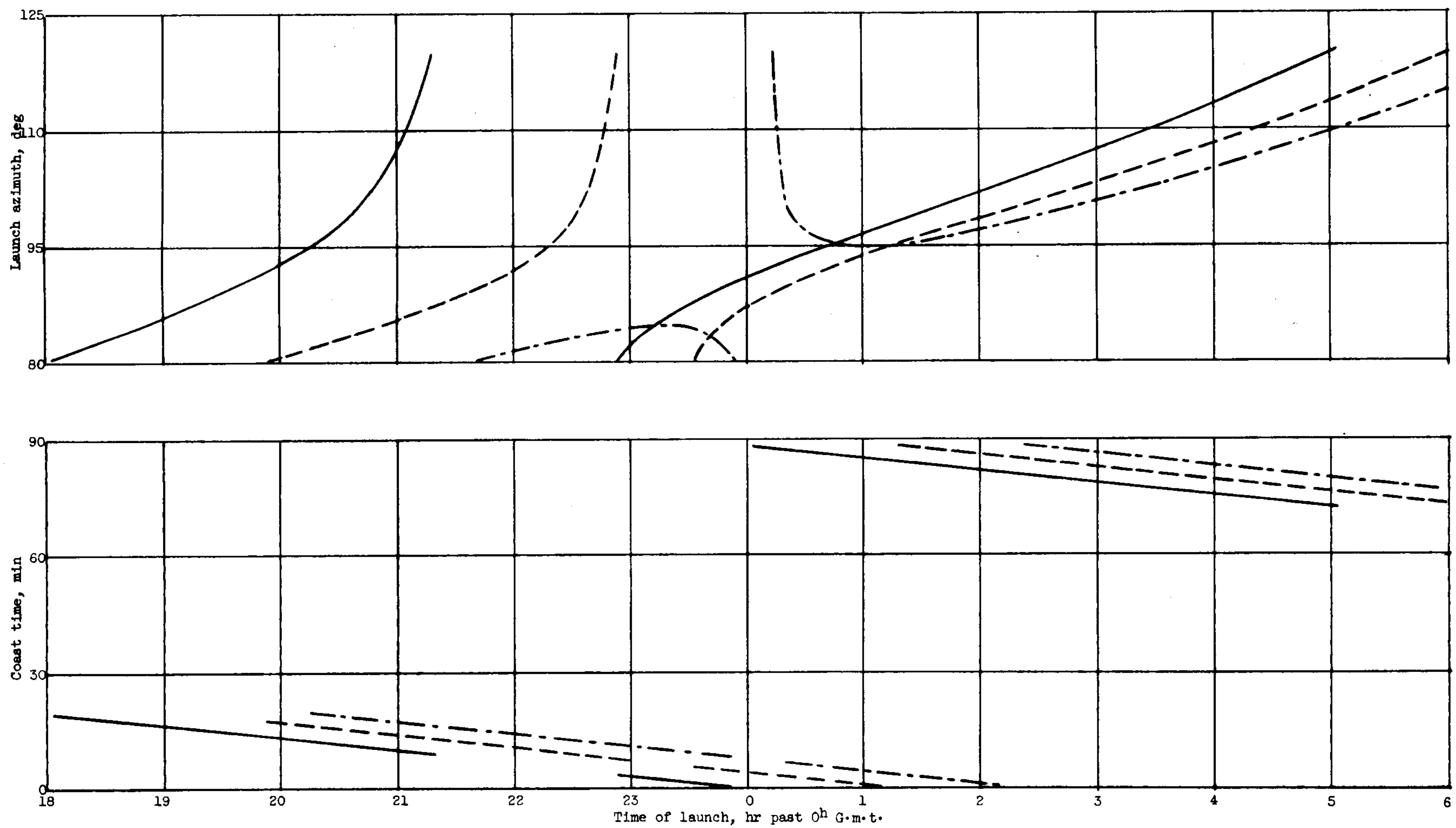

(b) 550 day trip time.

Figure 4. - Continued. Launch azimuth and parking orbit coast time as functions of time of launch for indirect ascent Jupiter trajectories. 1972 opportunity.

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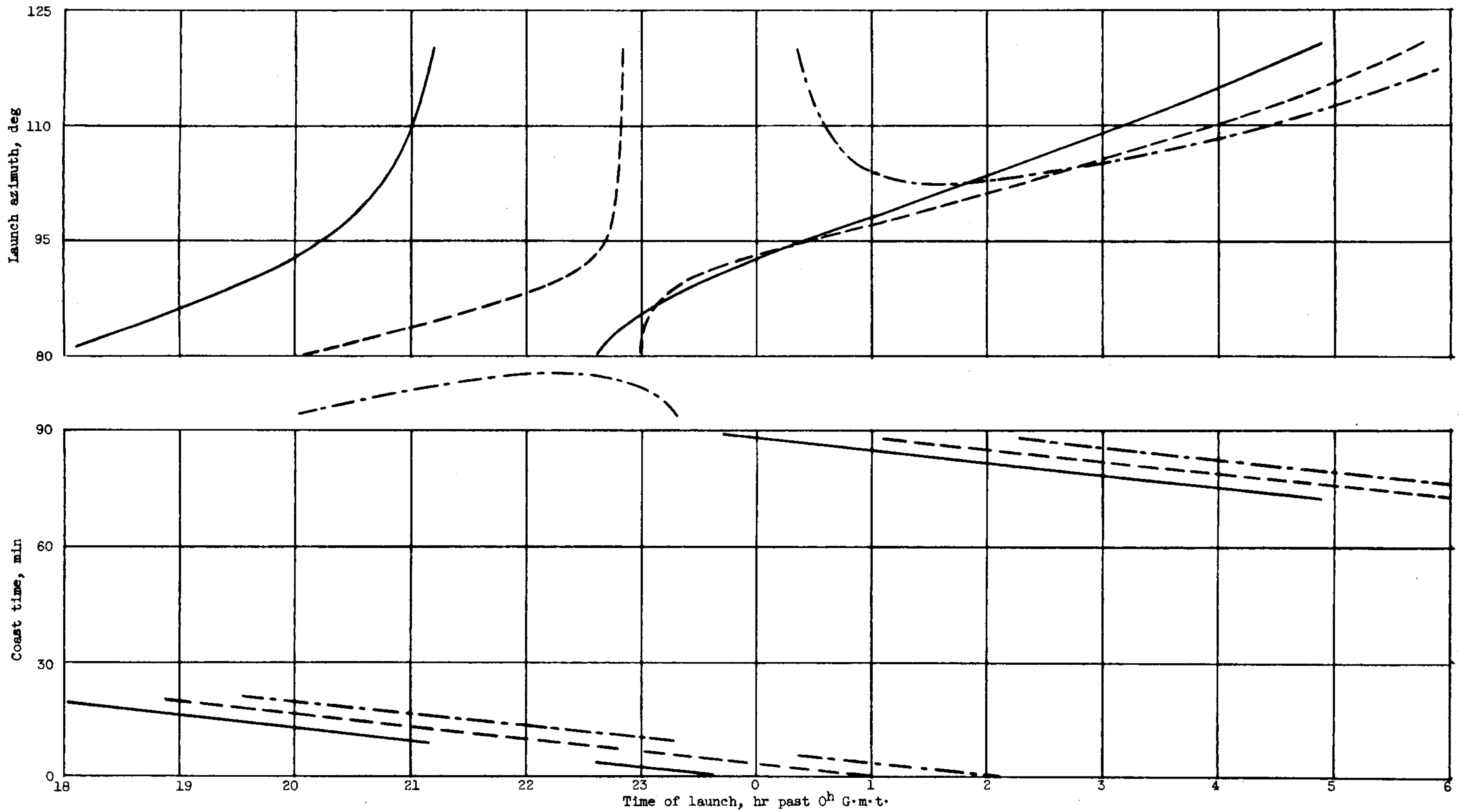

(c) 600 day trip time.

Figure 4. - Concluded. Launch azimuth and parking orbit coast time as functions of time of launch for indirect ascent Jupiter trajectories. 1972 opportunity.

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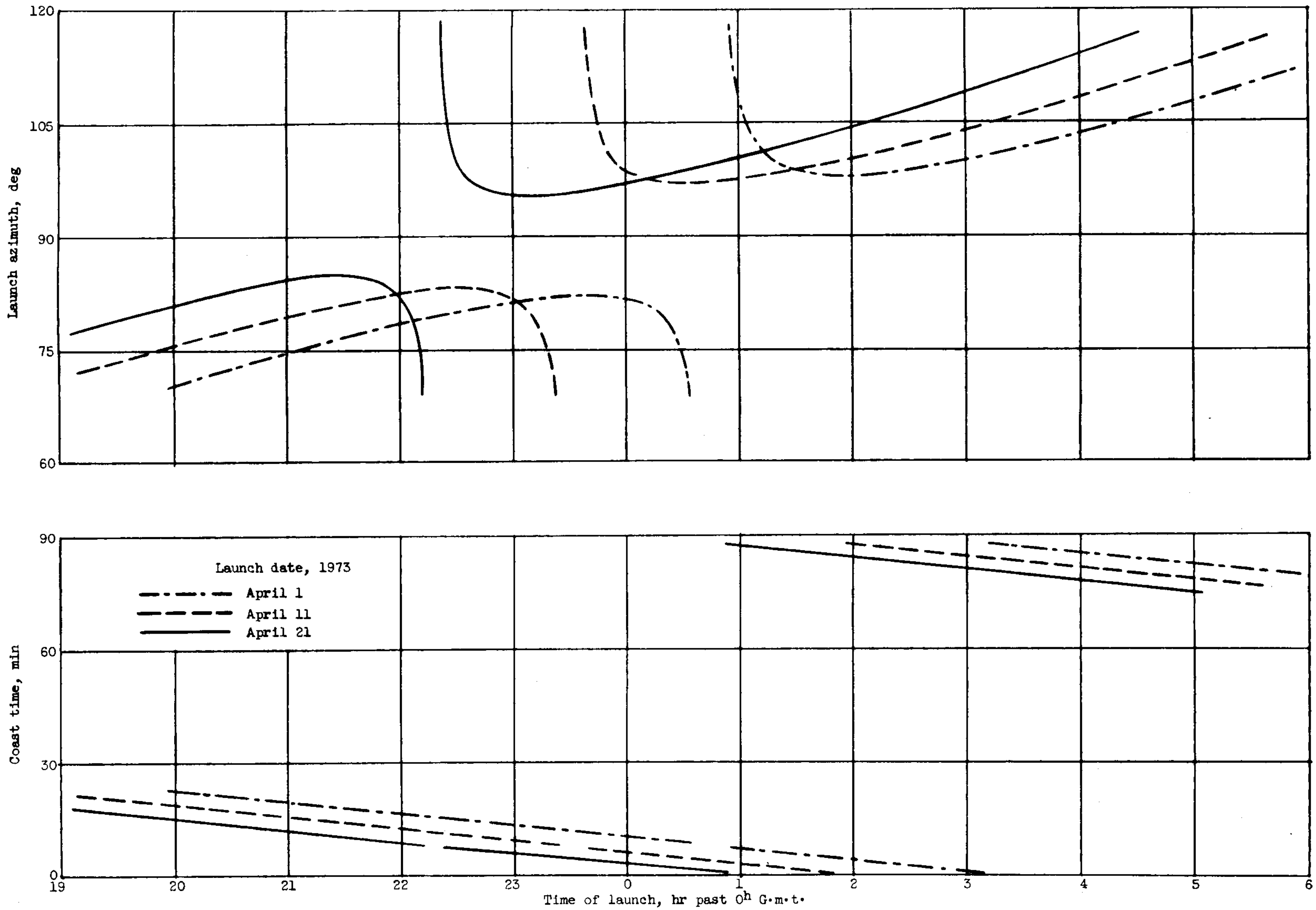

(a) 500 day trip time.

Figure 5. - Launch azimuth and parking orbit coast time as functions of time of launch for indirect ascent Jupiter trajectories. 1973 opportunity.

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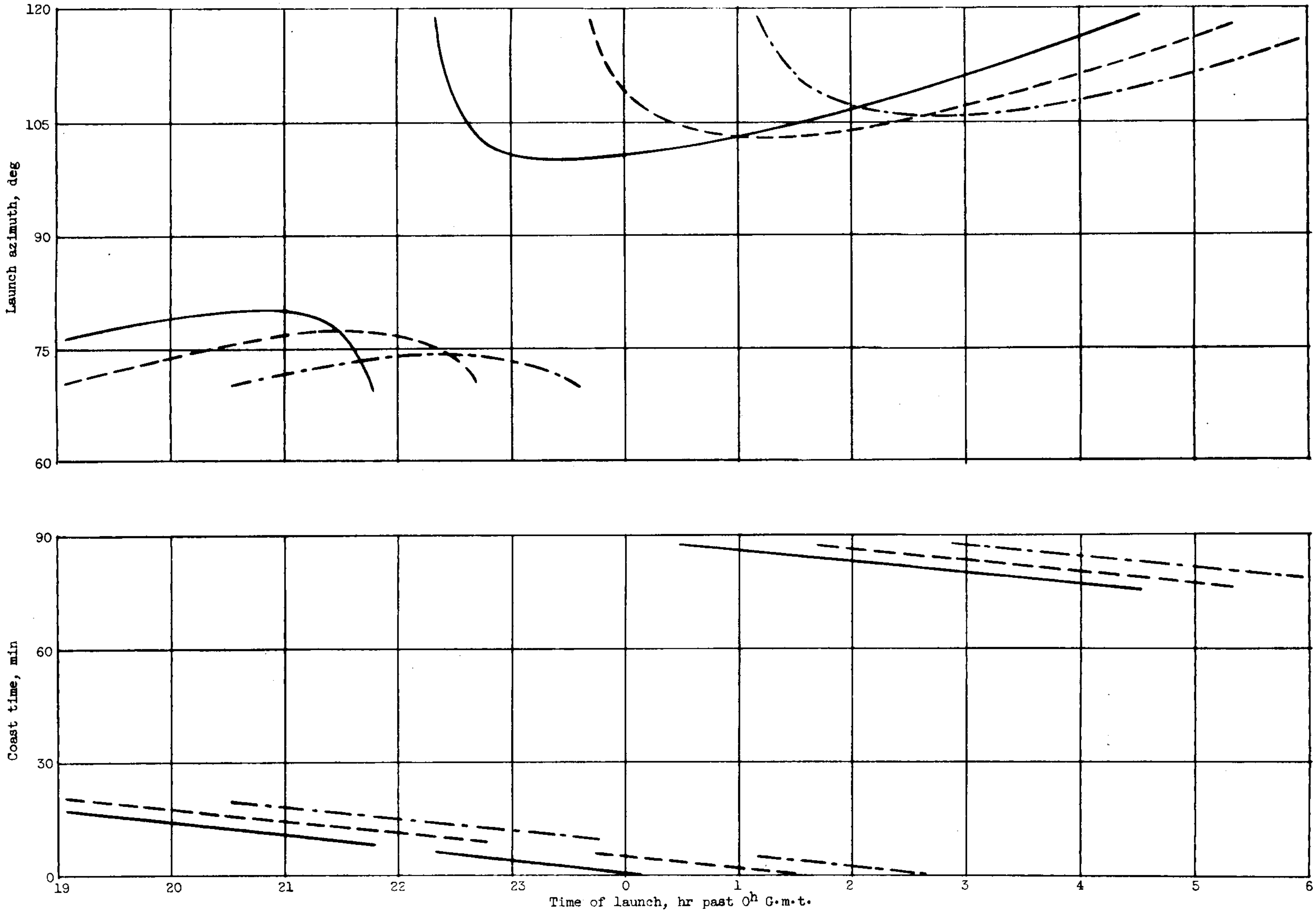

(b) 550 day trip time.

Figure 5. - Continued. Launch azimuth and parking orbit coast time as functions of time of launch for indirect ascent Jupiter trajectories. 1973 opportunity,

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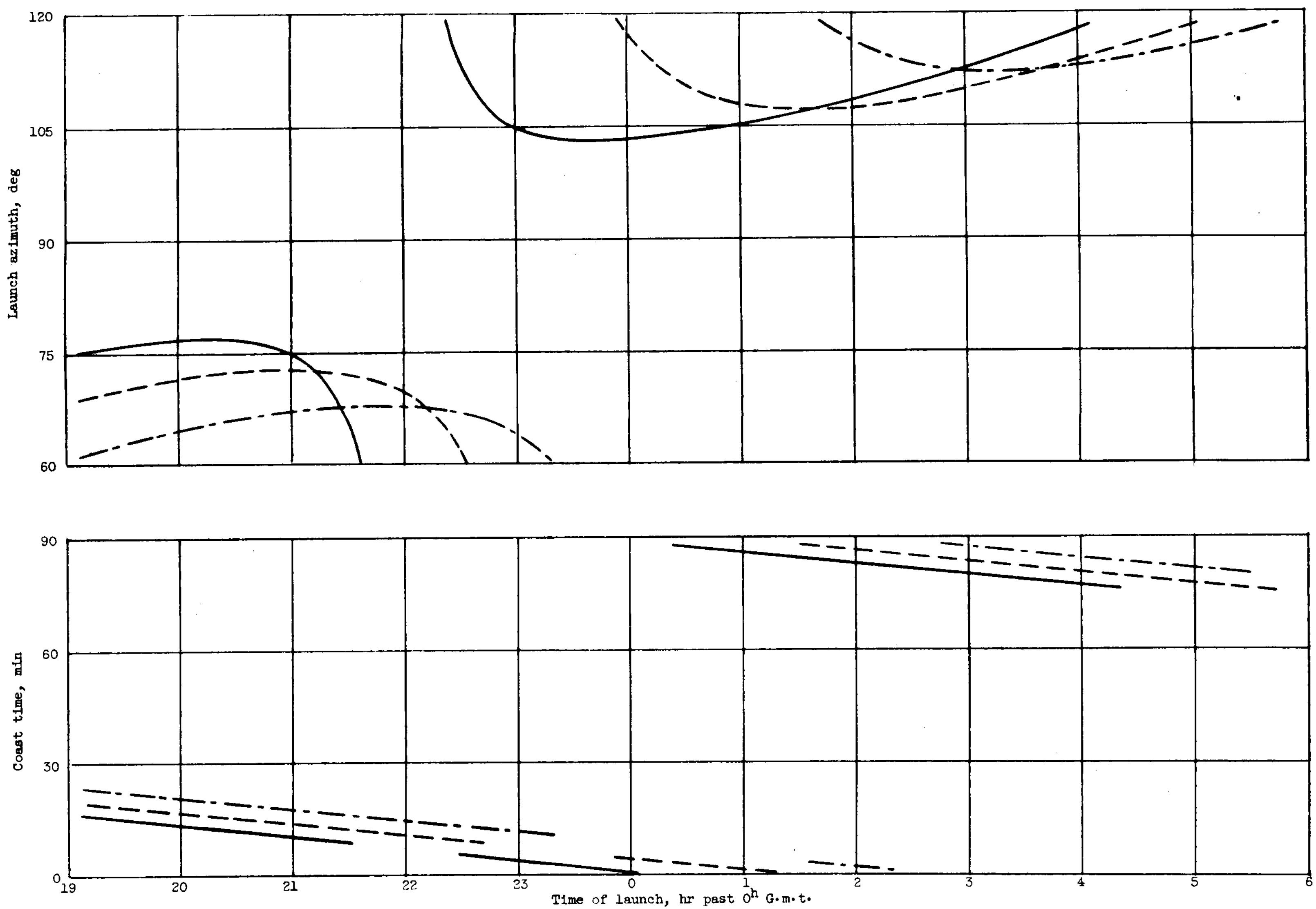

(c) 600 day trip time.

Figure 5. - Concluded. Launch azimuth and parking orbit coast time as functions of time of launch for indirect ascent Jupiter trajectories. 1973 opportunity.

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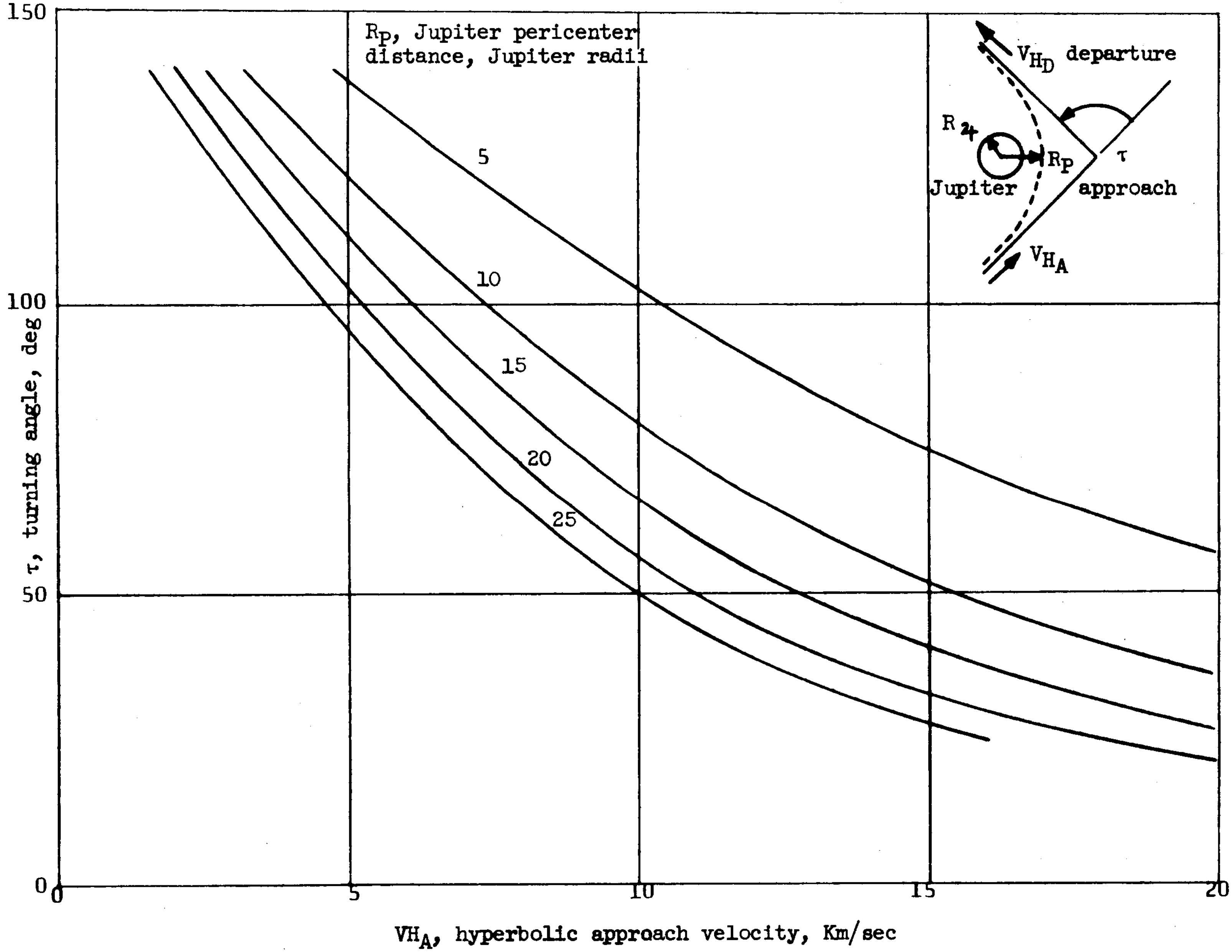

Figure 6. - Jupiter gravity turning angle as function of hyperbolic approach velocity.

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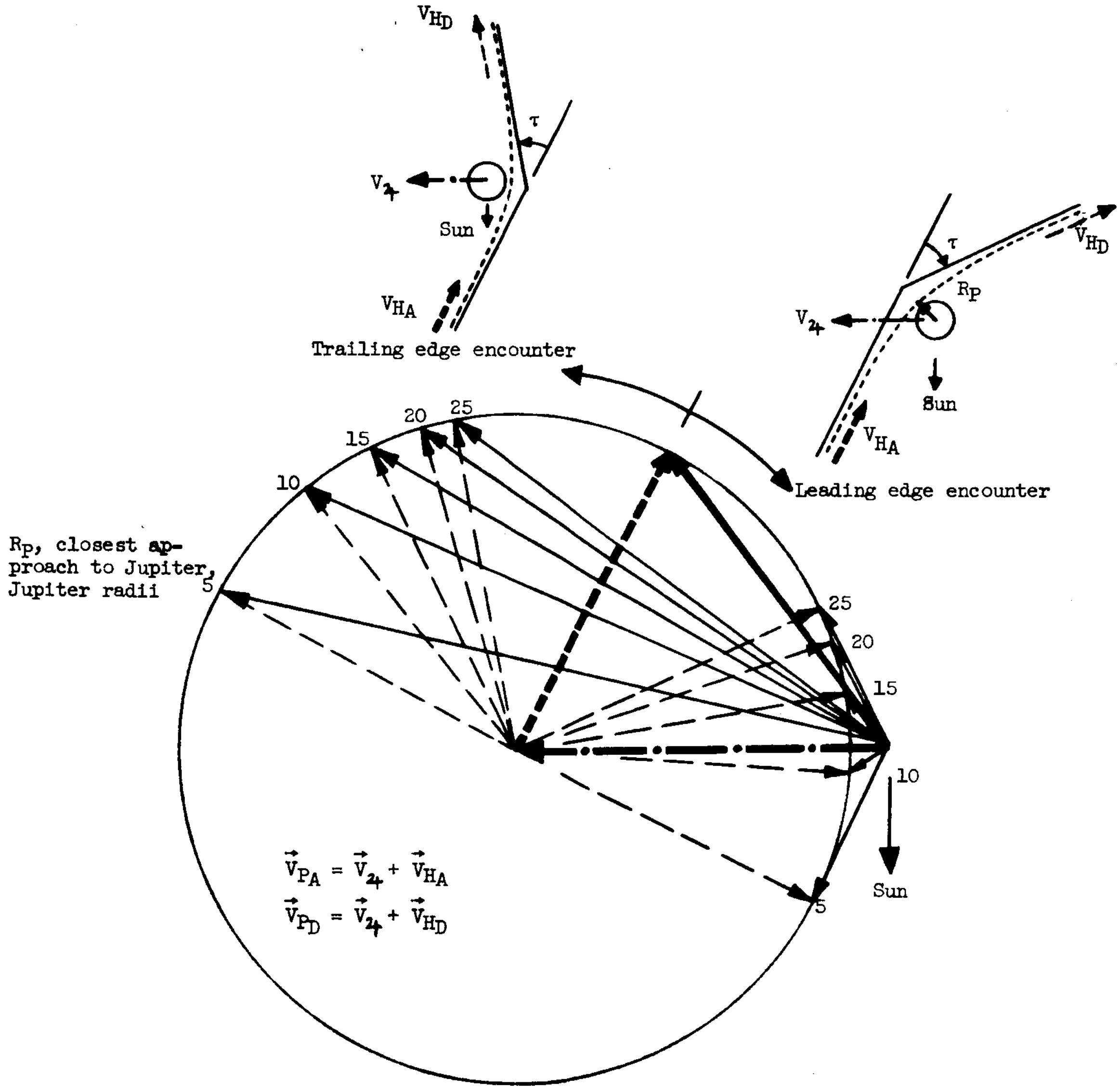

Key

$\vec{V}_{2\!\!+}$ Heliocentric velocity, Jupiter (13.62 Km/sec)

$\vec{V}_{P_A}$ Heliocentric velocity, probe at approach (13.26 Km/sec)

$\vec{V}_{H_A}$ Hyperbolic velocity, probe at approach (12.25 Km/sec) (relative to Jupiter)

$\vec{V}_{P_D}$ Heliocentric velocity, probe at departure

$\vec{V}_{H_D}$ Hyperbolic velocity, probe at departure (relative to Jupiter)

Figure 7. - Gravity turn geometry at Jupiter. Earth launch date, April 11, 1973. Trip time, 500 days.

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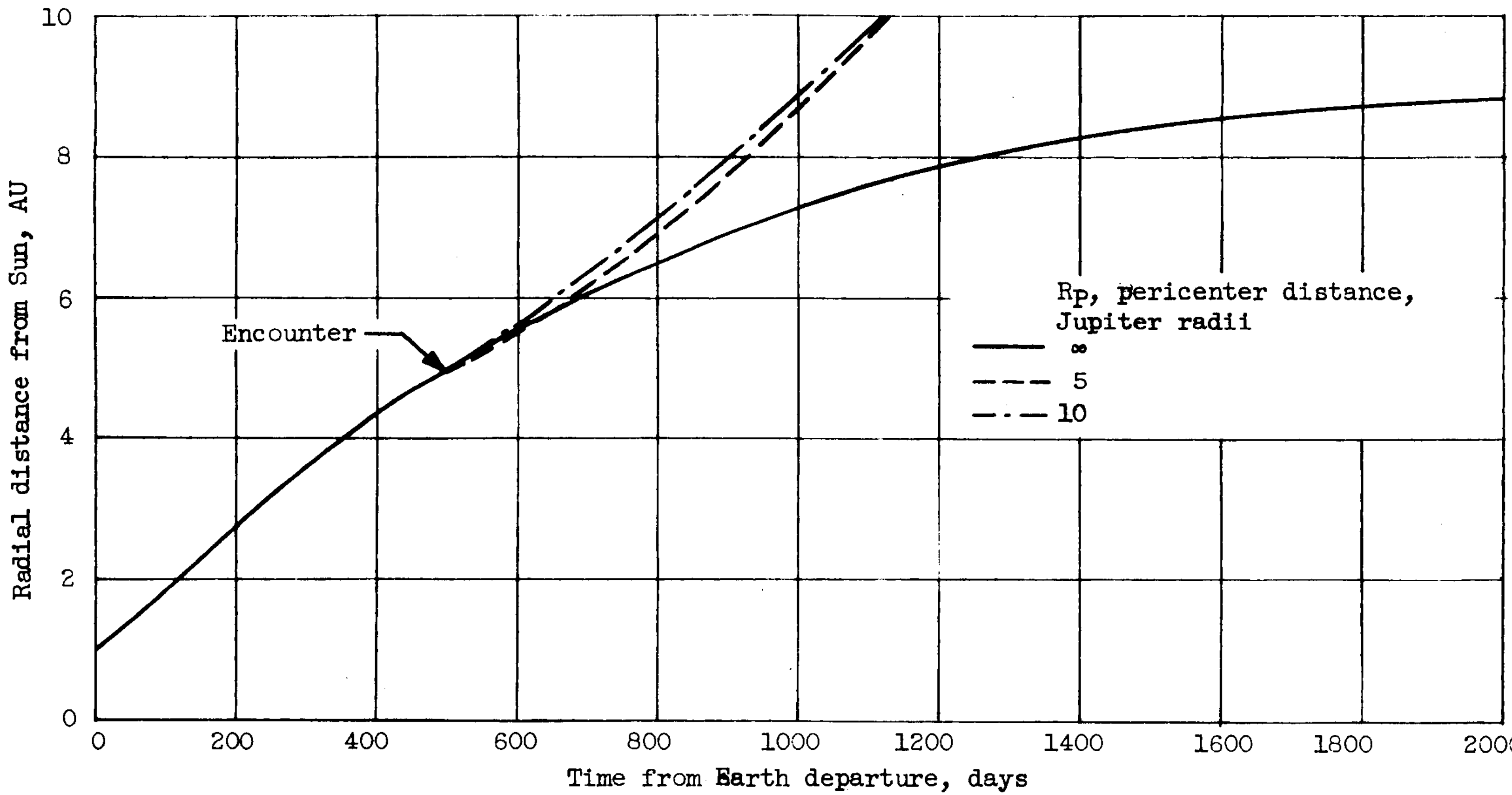

Figure 8. - Radial distance from Sun as function of time from Earth departure for 500 day Earth-Jupiter trajectory. Launch date, April 11, 1973

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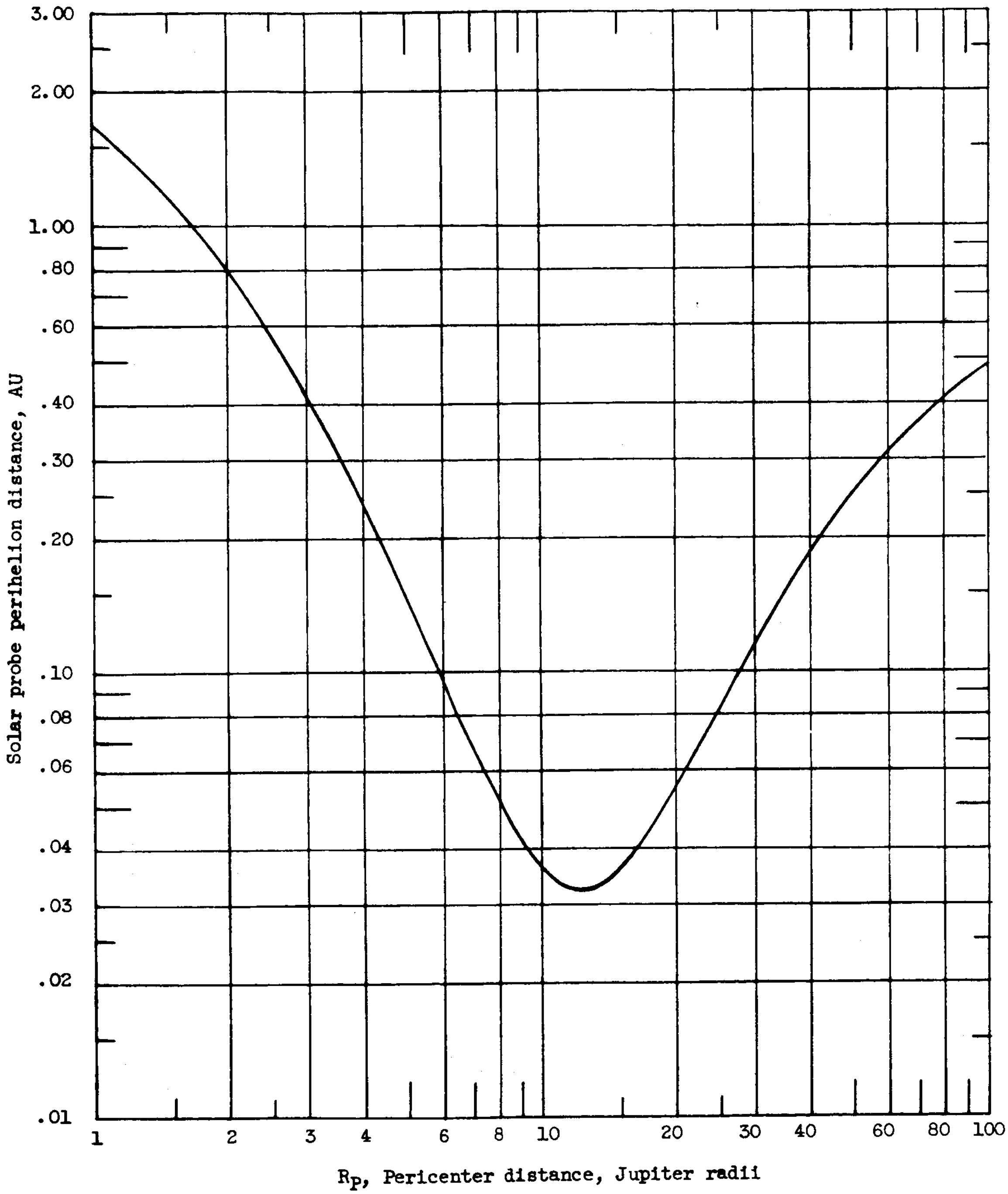

Figure 9. - Solar probe perihelion distance as function of Jupiter pericenter distance. Characteristic velocity, 49,250 fps. Earth-Jupiter trip time, 533 days.

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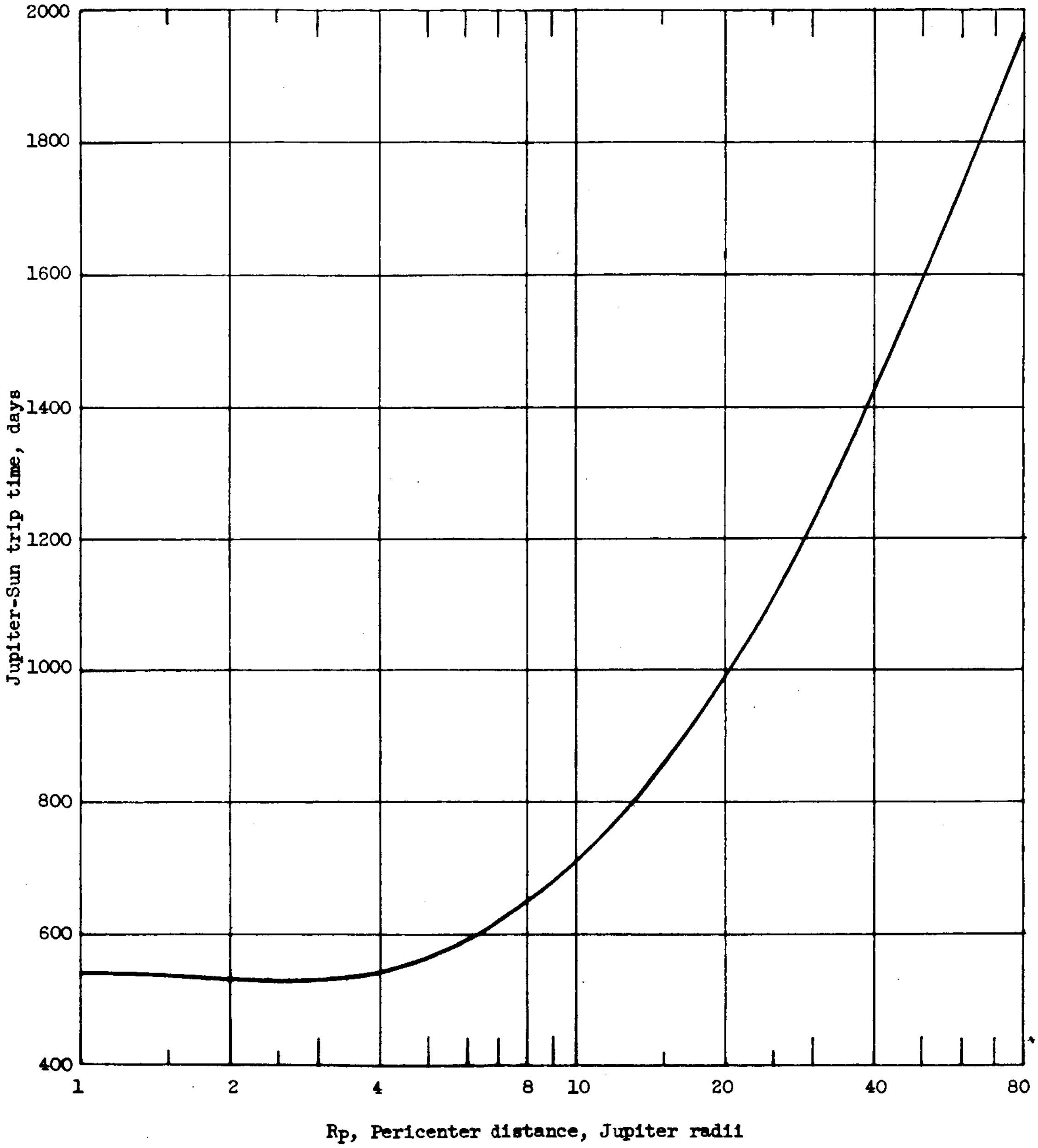

Figure 10. - Jupiter-Sun trip time as function of Jupiter pericenter distance for solar probe mission. Characteristic velocity, 49,250 fps. Earth-Jupiter trip time, 533 days.

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